WHAT IS SO SPECIAL ABOUT SHOEBOX HALLS? ENVELOPMENT, ENVELOPMENT, ENVELOPMENT

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In spite of many attempts to surpass the sound quality obtained from shoebox shaped concert halls, this traditional design continues to lead the pack in sound quality ratings. In Leo Beranek's careful surveys of concert halls and opera houses (1962, 1996, and 2004), four of the five highest ranked halls in the world have a rectangular shape. A deeper understanding of what differentiates them from surround halls, fan shaped halls, or many other configurations will enable designers and architects to achieve a higher level of acoustical excellence in modern concert halls.

"The prominent feature of the most successful halls is their rectangular shape."

Highly-rated halls

Based on surveys of musicians, conductors, and knowledgeable listeners Beranek (1996, 2004) ranks the five best halls as: Grosser Musikvereinssaal (Vienna), Symphony Hall (Boston), Teatro Colon (Buenos Aires), Konzerthaus (Berlin), and Concertgebouw (Amsterdam). Figures 1-5 from Long (2006) show sketches of these halls based on Beranek's work. Most were constructed in the late nineteenth and early twentieth centuries. Konzerthaus was originally built in 1821 and rebuilt in 1993 after having been destroyed in World War II. While there are other fine halls, most have similar features. In fact four of the next five top rated halls are also rectangular.

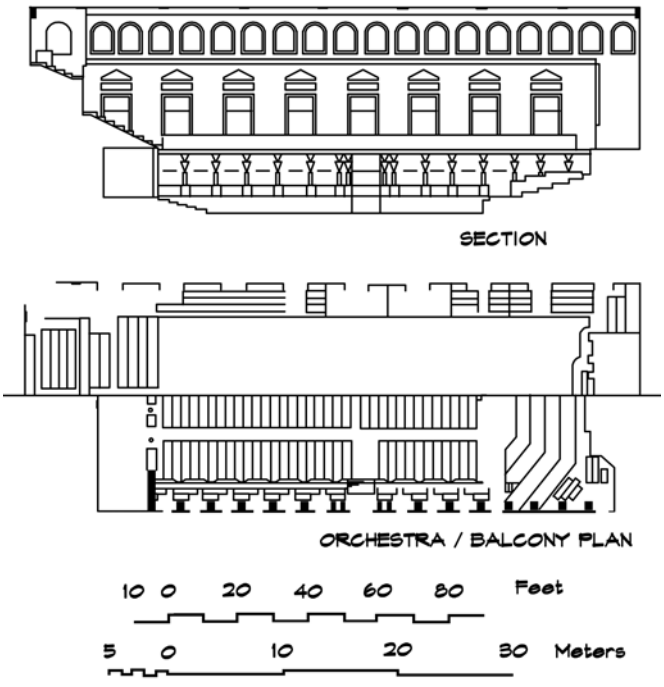

Fig. 1. Grosser Musikvereinssaal, Vienna, Austria (Beranek, 1996).

Technical factors in hall design

Studies by Ando (1985) and Beranek (1996, 2004) have identified quantitative factors that contribute to hall quality. In approximate order of importance, these are: (1) *listener envelopment*, that is, the sense of being surrounded by sound, in particular, in the time period greater than 80 milliseconds after the arrival of the first sound; (2) *reverberant character*, usually quantified in terms of the reverberation time; (3) *diffusion*, an important factor contributing to envelopment; (4) *sound strength*, as determined by taking measurements at various seats throughout the hall of sound delivered from a

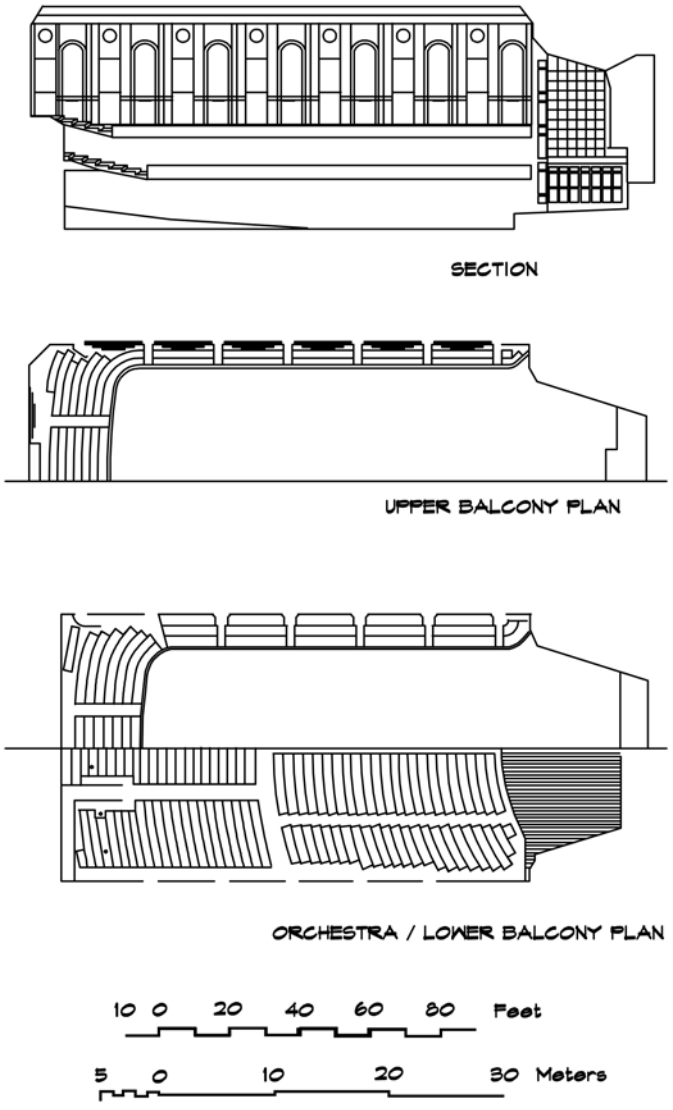

Fig. 2. Symphony Hall, Boston, Massachusetts, United States of America (Beranek, 1996).

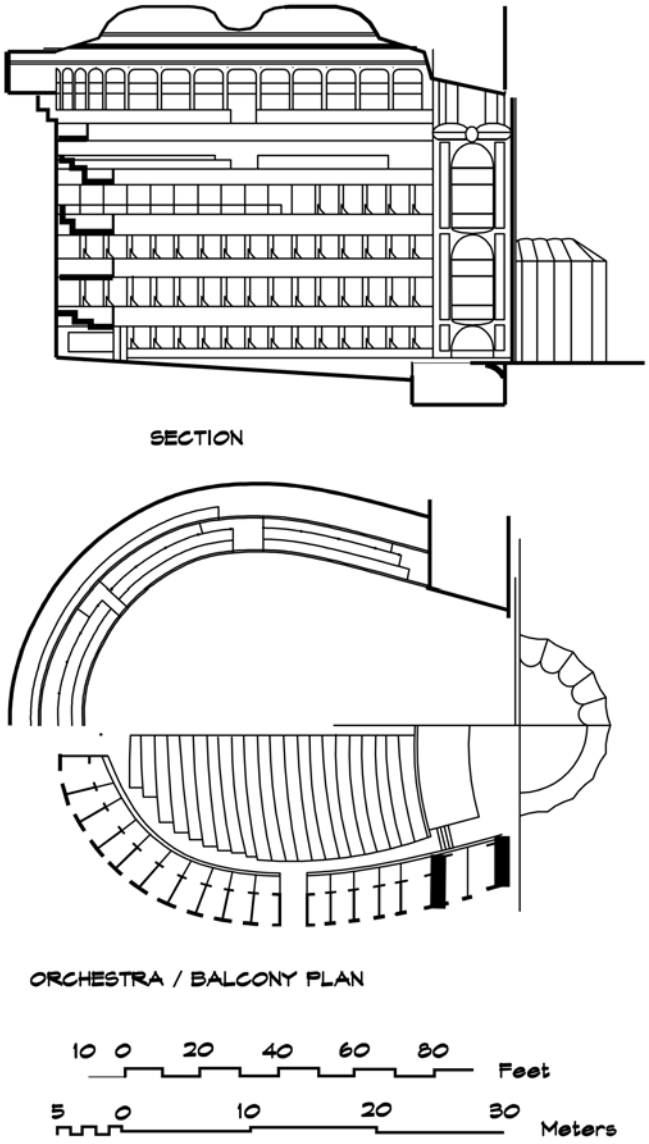

Fig. 3. Teatro Colon, Buenos Aires, Argentina (Beranek, 1996).

fixed source on the orchestra platform; (5) *clarity*, the strength of the initial sound along with early reflections arriving soon thereafter; and (6) *warmth*, the strength of the bass. Additional contributing factors that are not usually considered in these ratings include audience comfort, a low level of background noise, clear sightlines, and convenience. The absence of any of these qualities can offset the other positive factors.

Physical characteristics of successful halls

The features common to successful halls continue to be a subject of spirited debate, study, and technical measurement. Every rule seems to have at least one exception, but there is enough consensus that a very convincing case can be made.

The prominent feature of the most successful halls is their *rectangular shape*. Among the five best, only Teatro Colon varies—having the horseshoe shape of a classic European opera house. The best halls are *narrow*, usually less than 75 feet wide. Vereinssaal is only 65 feet, Symphony Hall 75 feet, Konzerthaus 68 feet, and Teatro Colon 80 feet. The exception is Concertgebouw at 91 feet. The narrow parallel side walls in rectangular halls provide early reflections that increase clarity, along with later side reflections that surround or envelop the listener. The latter reflections include not only the first reflected sound but also additional multiple reflections extending out in time.

The best halls also have *flat* or *gently sloping floors* and *elevated orchestra platforms*. Most platforms are at or above the level of the last row of seats. This is in contrast to a legitimate theater where the seating is raked for better sightlines. A typical stage height in a legitimate theater in the United States is 42 inches, based on the average seated eye height of about 44 inches. In Vereinssaal the orchestra platform is 39 inches, however, the main floor is flat except in the rear where the last few rows rise to about the level of the orchestra. The platform height at Konzerthaus can vary between 31 and 95 inches, but the main floor seating plane is not raked. At Concertgebouw the platform is 59 inches and the floor is flat. At Symphony Hall the platform is 54 inches high and there are two seating configurations. In summer, for the "Pops" concerts, the floor is flat and patrons are seated around tables. In winter, a plywood floor is installed that rises at the rear to a height just above that of the orchestra. Teatro Colon has a gently raked floor and a pit filler that can be raised and lowered. The stage height is not given by Beranek (2004), but appears in photographs to be about 42 inches, consistent with its primary use as an opera house. The seats rise at the rear to about the same height as the stage.

Envelopment is enhanced when there are *wall surfaces available to create multiple reflections* in a plane just over the heads of the audience. This allows sound reflections to be sustained in this horizontal plane without being absorbed by the audience. When the seating is steeply raked or when the orchestra is seated on a low platform, side reflections are grounded out in the seating area after the first reflection. It can be observed that the most highly rated halls have reflective surfaces located in the band above the first floor seating in the same horizontal plane as the orchestra. It is likely that this feature in Concertgebouw helps counteract the width of the room. The wall surfaces need not be smooth; indeed, scattering by diffuse objects can be helpful to envelopment. All of the best halls have significant side wall diffusion.

The reverberant character is quantified by the reverberation time—the time it takes for a sound to die out. In large concert halls, when fully occupied, *the reverberation time ranges from 1.8 to 2.2 seconds in the 500-1000 Hz octave bands*. Shorter times are preferred for music in the classical style (Bach, Mozart and Haydn), which was originally performed in smaller rooms. Longer times are preferred for romantic music (Schubert, Mendelssohn, and Brahms). The reverberant character of these halls is generally uniform. At Vereinssaal, Konzerthaus, and Concertgebouw the mid-frequency reverberation time is 2.0 seconds. Symphony Hall is 1.9 seconds. The exception is Teatro Colon at 1.6 seconds, where lower values are preferred for better speech intelligibility.

Successful halls usually *limit the number of seats* to no more than 2400 and preferably to fewer than 2200.

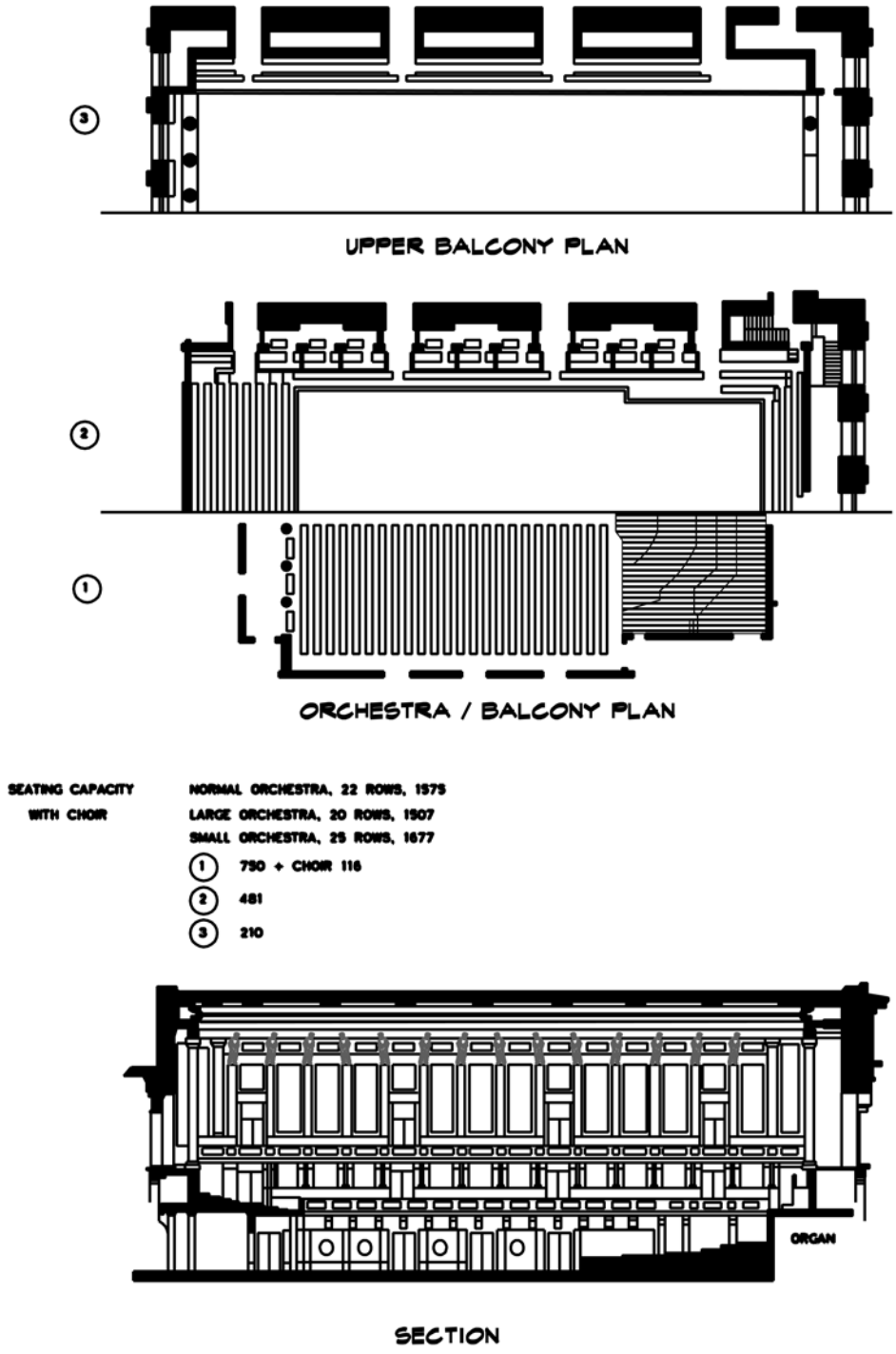

Fig. 4. Konzerthaus, Berlin, Germany (Beranek, 1996).

Vereinssaal has 1750, Teatro Colon 2487, Konzerthaus 1575, and Concertgebouw 2037. The exception is Symphony Hall at 2625. The average seating capacity of the top five is about 2100 and the top ten about 2000. Sound strength is greatest in smaller capacity halls since the audience represents the largest absorbing surface.

Ceiling heights, as measured from the main floor in areas not covered by balconies, *are usually greater than 50 feet*. Vereinssaal is 57 feet, Symphony Hall 61 feet, Konzerthaus 58 feet, Concertgebouw 52 feet, and Teatro Colon 87 feet. All of these *ceilings are highly diffusive*—they are designed to scatter sound in many directions. Additional diffusive elements such as columns, statuary, and chandeliers are frequently added.

Another important factor is the *ability of the orchestra to hear itself*. Reflective surfaces located above and around the orchestra area enhance the musicians' ability to hear each other. In rectangular halls the orchestra is located at one end of the room up against highly reflective surfaces. In these halls the sound is confined to a lateral angle of about 90 degrees while an orchestra in the middle of a room radiates into the full 360 degrees (Hidaka *et al*., 2008). This increases

the sound strength in the rectangular rooms by about 6 dB compared to the surround halls.

Non-rectangular halls

There are other room shapes used in concert hall design. The most common is the surround hall where the audience seating surrounds the orchestra. This style has been used in Berlin Philharmonic Hall, Suntory Hall in Tokyo, and Disney Hall in Los Angeles. Figure 6 shows a sketch of Berlin Philharmonic Hall. Non-rectangular halls can be designed with the goal of achieving the same technical factors as those present in shoebox halls. In the areas of reverberation and clarity, surround halls can achieve results comparable to those found in rectangular halls. Hidaka *et al.* (2008) recently published a detailed comparison of measured data in these two types of halls. Surround halls are not as successful as rectangular halls in achieving envelopment, source strength, and minimizing seat to seat variation. This is particularly evident with directional instruments such as the French horn, trumpet, and piano (with its reflecting board sending the high frequency sounds forward), as well as a soprano voice. In these factors the Hidaka *et al.* (2008) study shows clear differences.

Shoebox halls

Some acousticians and architects are still building halls in the shoebox style. Sala São Paulo in Brazil is a good recent example. The late Russ Johnson, acoustician for Sala São Paulo, told me he thought it might be his best hall. Seiji Ozawa Hall in Lenox, Massachusetts is another fine example.

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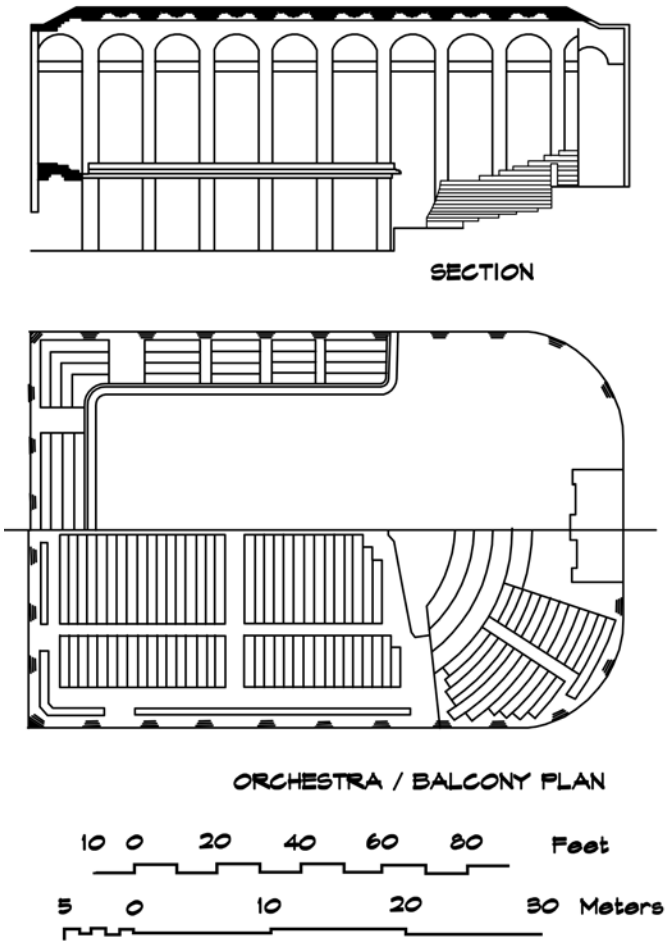

Fig. 5. Concertgebouw, Amsterdam, Netherlands (Beranek, 1996).

It is encouraging that the testimonial evidence is supported by the technical studies. It seems clear that the inclusion of a reflective band above the first floor seating helps maintain lateral reflections and envelopment. This combination of a raised orchestra platform and low rake angle for the seating is a common feature in the world's best halls. In the balconies reflective bands are also present in rectangular rooms and are augmented by overhangs from the upper balconies and ceilings above. If acoustical excellence is of prime importance and shoebox halls sound best, we should be building more of them.AT

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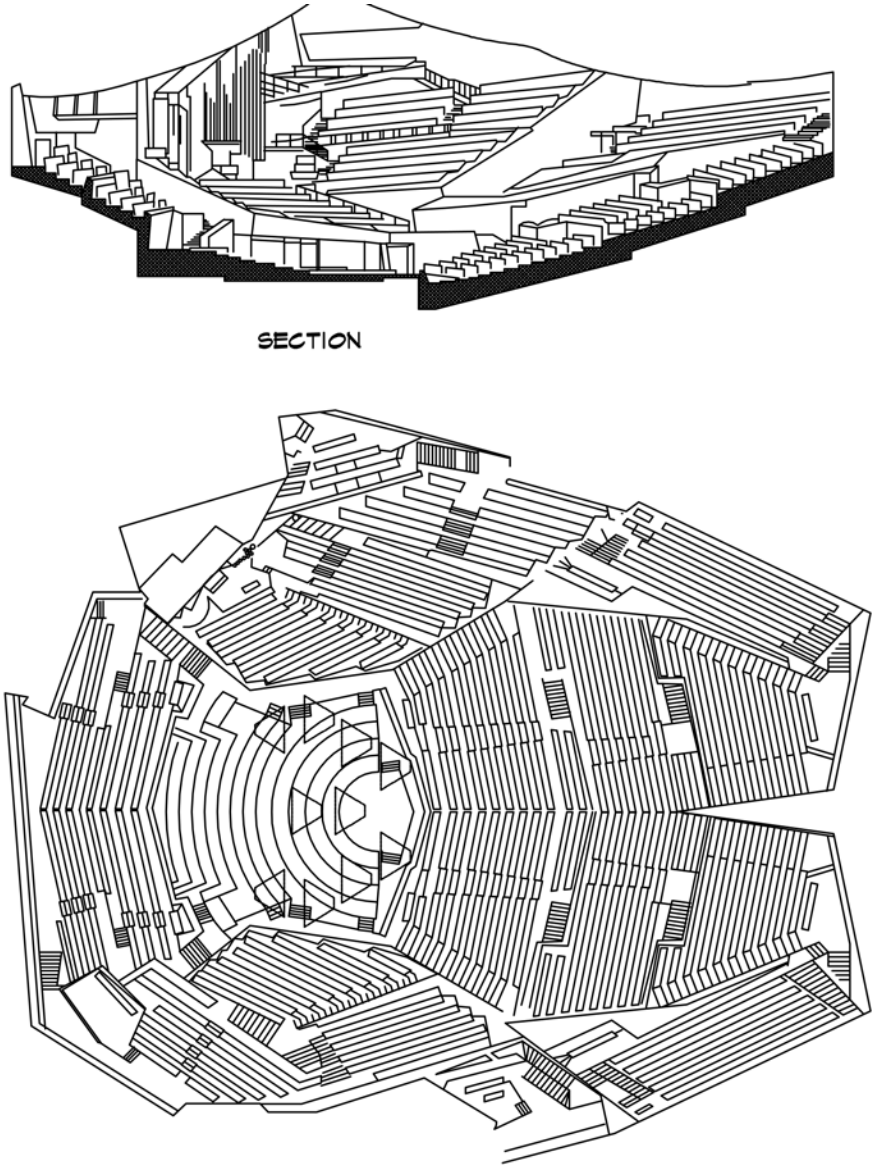

Fig. 6. Philharmonic Hall, Berlin, Germany (Beranek, 1996).

Marshall Long received a BSE from Princeton University in 1965, attended the University of Grenoble in France and the University of Madrid in Spain in 1966, and received MS and Ph.D. degrees in engineering from UCLA in 1971. While still a graduate student, he founded his own consulting firm, now in its 38th year. Marshall Long Acoustics specializes in architectural acoustics, audiovisual design, noise and vibration control, and other technical areas related to acoustics. He enjoys sailing, judo, soccer, reading, and writing, and is living with his family in Sherman Oaks, California. He was recently elected a Fellow of the Acoustical Society of America.